MEASURING BIRD MIGRATION USING SPATIAL AND TEMPORAL COUNTS

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Abstract:
This paper traces our attempts to develop an index of migration from the Project FeederWatch data, using species known to be either migratory or nonmigratory. A simplistic analysis, averaging over observers, seems to work well. A more sophisticated analysis, taking into account observer variability, does not discriminate well between migratory and nonmigratory species.

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Introduction

In the Northeastern U.S., each fall and spring are heralded by large flocks of birds migrating between their summer and winter territories. Behavior ranges from migration of the entire population, to migration of only a subpopulation and nonmigration. Even in nonmigrant species, some years may see movement of a large portion of the population - termed irruption.

Bird migration can provide important information about population dynamics, interactions with other species, disease transmission, habitat use and other features of bird populations that are of interest to ornithologists, environmental scientists, and nature lovers.

While much information has been gained from studies that include tracking of banded or radio-collared birds , the expense involved prohibits wide-spread use of these methods. However, the availability of a large number of knowledgeable amateur bird-watchers across North America, who are willing to assist with data collection of many types, enables North American ornithologists to conduct studies that involve spatial and temporal information with a high degree of resolution (at least compared to the data available on terrestial animals). Such networks of birders have provided information on such interesting features as the introduction and spread of alien species and the growth or decline of populations in certain locales. Can the data be used to measure migratory behavior?

Project Feederwatch, initiated in 1987 by the Cornell Sapsucker Woods Laboratory of Ornithology, has a large database of information about several bird populations from volunteer participants across the U.S. and southern Canada. These data, collected each winter from November through March, are counts of the number of birds of each species reported by each participant on a biweekly basis. These data with their wide spatial coverage, and fine temporal resolution, seem ideally suited to measure migratory behavior, although the timing of the data collection, from late fall to early spring, might miss the migration periods for some species.

Project Feederwatch is described in some detail in XXX. *The Amateur Scientist* column of *Scientific American*, April, 1997 (Carlson, 1997) provides a nice overview of Project Feederwatch and several other ``Citizen Science" projects run by the Cornell Lab of Ornithology.

Project Feederwatch participants are instructed to observe their feeders for two consecutive days, biweekly from mid-November to mid-March, and report the maximum number of birds of each species observed simultaneously at the feeder. The participants also record a rough measure of observation effort - an indicator of whether or not they viewed during the morning and/or afternoon of each of the two viewing days. As well, there are a number of concomitant variables, such as the type of birdfood offered, and data about the household, such as location, number of feeders, and so on. Climate information was added to the data using REF. There are over 2000 participants across the U.S. and Canada.

Species abundance maps created from the Project Feederwatch data can be viewed on the Web at http://birdsource.cornell.edu/pfw/Abundance_maps_pfw/index.html. A look at the animated monthly maps gives a clear story for some migratory species, for example the Common Grackle. Grackles are very sparse on the November, December and January maps. More grackles appear in February, and abundance is very high in March. Clearly, the data collection period has missed the southward migration in the Fall, but records the northward migration in early spring. By contrast, there is little change in the monthly maps for the Northern Cardinal, a nonmigratory species.

The animated maps suggest that there might be some way to characterize migratory behavior from the Project Feederwatch data. If a numerical index of migration can be developed which clearly delineates between migratory and nonmigratory species, this could be useful in several ways. Changes in migratory behavior, which might be induced by competition from an introduced species, a new disease, or other changes in the environment could be tracked by determining if the index of migration changes over time. Irruptions could be quantified. And more subtle behavioral changes, such as local deviations from otherwise widespread migratory behavior, may be detectable.

This paper traces our attempts to develop an index of migration from the Project Feederwatch data, using species known to be either migratory or nonmigratory. A simplistic analysis, averaging over observers, seems to work well. A more sophisticated analysis, taking into account observer variability, does not discriminate well between migratory and nonmigratory species.

Developing an Index of Migration

Suppose that we could obtain full data on the weekly species abundance at each locality for the entire year for a migratory bird species. In the summer range of the species, we expect more birds in the summer weeks and few or none in the winter. In the winter range of the species, we expect more birds in the winter weeks and few or none in the summer. If both the summer and winter range are within the area covered by our data, we ought to be able to plot species abundance versus date at the two extremes of the range and observe the rise and fall of abundance with season. In a nonmigratory species, we would not expect any seasonal differences. This is the intuitive basis for the development of a migration index.

The reporting periods were staggered so that weekly data are available over most of the observation area. Participants report a coarse measure of effort and the maximum number of birds observed of each species.

The Project FeederWatch data are unique in the extent of their spatial and temporal coverage. It is not necessary to include the full migratory period or range as long as some population movement can be documented. An important feature of a migration index developed from these data is that it can be applied to a subset that does not include the complete migration period and path.

Statistical analysis was first attempted by Bernstein in 1998. This analysis focused on average counts over all observers. In 1999, the analysis was continued by Cottrell, using a random effects approach that modeled the within observer counts. In both cases, the index of migration was a measure of how seasonal effects varied from north to south.

Both Bernstein and Cottrell developed their indices using several species of known migratory and nonmigratory behavior. The known migrants are the common grackle and redwing blackbird, both of which have winter range in the southern U.S. and summer range in the northern US and Canada. The known nonmigrants are northern cardinals and downy woodpeckers.

Analysis of Climate Zone

In migratory species, we expect the "center" of species abundance to move southwards during the colder months, and northwards during the warmer months. In nonmigratory species, we expect little change in the "center" during the winter, although there may be some shift if there is differential mortality due to, for example, food scarcity in some regions.

Migratory species do not appear to respond strongly to current weather conditions, but may respond to a recent history of mild or severe weather. We therefore used the 1961-1990 mean minimum January temperature (**MeanMinT**) for the ZIP code of each participant as an indicator of winter severity experienced at that location. We expect that participants with a lower **MeanMinT** will observe more migratory birds in fall and spring, and fewer in the winter. Conversely, participants with a higher **MeanMinT** will observe more migratory birds in the winter.

To define the "center" of the bird population, we need to define both what we mean by "location" and what we mean by "center". For our purposes, winter severity appears to be more meaningful than location. Hence, we attach to each observed bird the value of **MeanMinT** at its location. (This attaches the bird to a climate zone, rather than a longitude, latitude or exact location.) The "center" on week j is then a typical or average value of **MeanMinT** for the birds observed at week j. To be explicit, it is computed by the following algorithm:

1. Observer i has **MeanMinT** value T_i based on the location of the observation site.

2. At reporting week j each bird observed by observer i is assigned value T_i
3. For each week, the MeanMinT is averaged over birds, to obtain the average climate zone for that week.
4. If we denote the number of birds spotted by observer i in week j as n_{ij}, then the average climate zone in week j can be computed as $\frac{\sum_i n_{ij} T_i}{\sum_i n_{ij}}$.

Note that this measure of "center" is conditional on observer location. It does not reflect the "center" of the entire bird population over the entire eastern North America, but rather the "center" of birds seen by observers at their fixed locations. Hence, interpretation relies on the set of observers remaining stable over a single winter, and on the randomness of the missing data with respect to observer location.

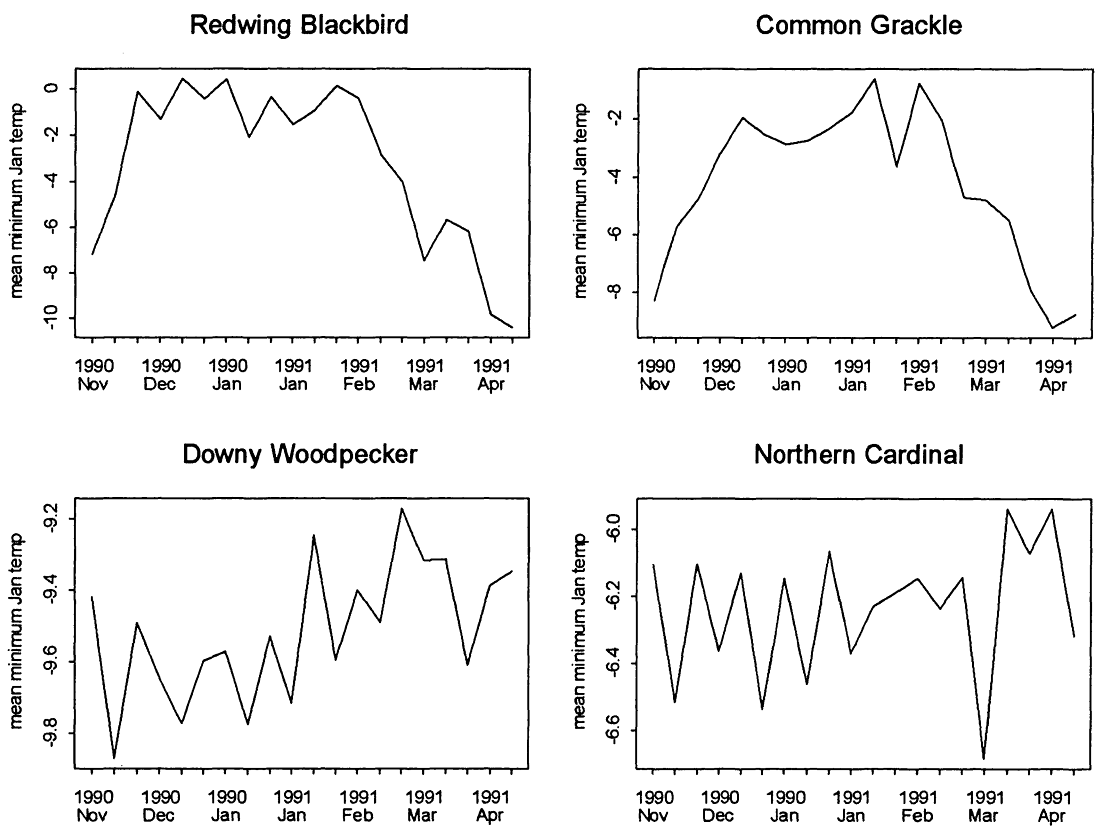

Figure 1: *Average climate zone of observed birds by week for two migratory species (Redwing Blackbird and Common Grackle) and two nonmigrant species (Downy Woodpecker and Northern Cardinal) for winter, 1990. The migratory species move towards warmer climate zones in the winter, in a characteristic "cap" shape. The nonmigant species do not show the "cap" pattern. Note also the greatly expanded "y" axis for the migratory species, indicating movement between differing climate zones.*

Figure 1 shows the 1990 data by week. The pronounced jaggedness of the plots for the nonmigrants appears to be due to the interleaving of the alternate week reporting series. Figure 2 shows the same data plotted to the same scale on the "y-axis" (**MeanMinT**). The nonmigrants clearly are not moving between climate zones.

The plots suggest that an index of migration might be based on a quadratic fit to these curves. One possibility is to use a test that the quadratic coefficient is negative. However, this does not take into account the "distance" moved. (Here "distance" would be the number of degrees of temperature change.) Another possibility is to consider the difference in fitted values from mid-winter to an average of the early and late winter values.

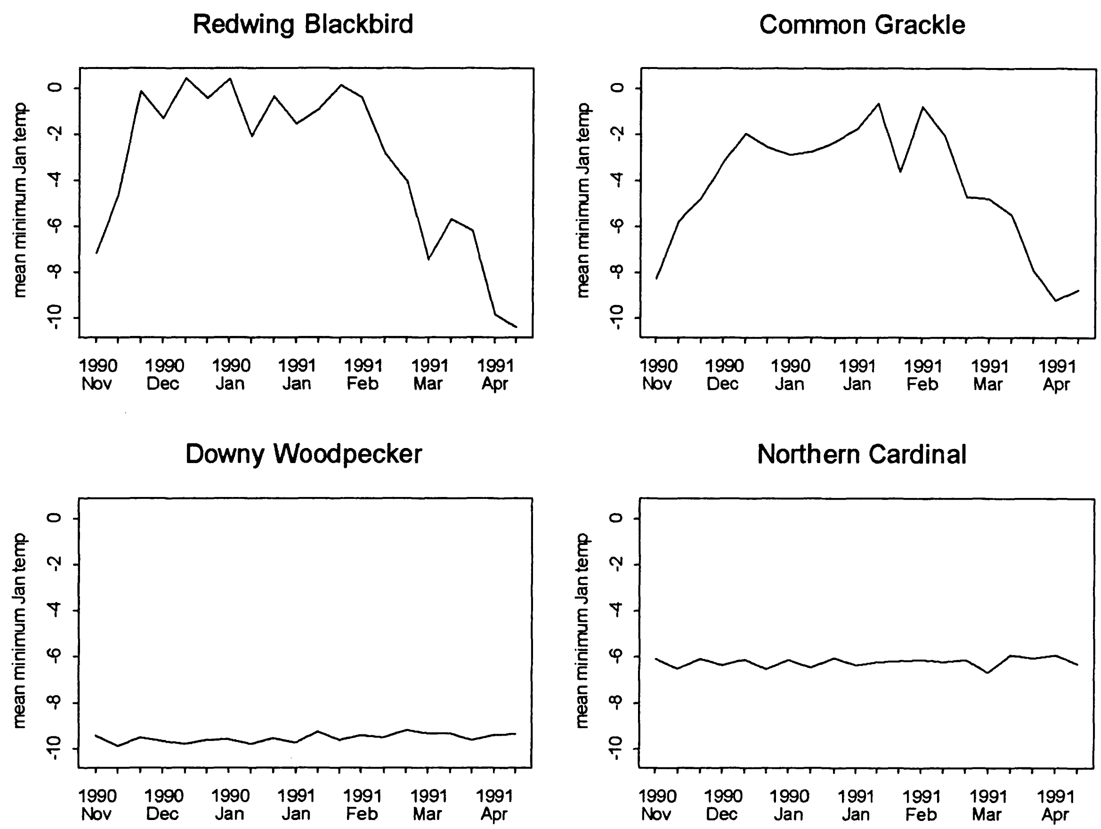

Figure 2: *Average climate zone of observed birds by week for two migratory species (Redwing Blackbird and Common Grackle) and two nonmigrant species (Downy Woodpecker and Northern Cardinal) for winter, 1990, plotted against a common "climate zone" axis measured by mean minimum January temperature.*

Figure 3 displays the p-values for the test for negative curvature of the plot of center of mass versus week for each of the 4 species, by year. P-values near zero imply strong negative curvature which indicates migratory behavior. The p-values for the migratory species, Redwing Blackbirds and Common Grackle, are very small, as would be expected. Downy Woodpeckers display a bi-annual cycle of migratory and nonmigratory behavior. Northern Cardinals have nonsignificant tests for negative curvature, providing support for nonmigratory behavior throughout this period.

Figure 4 displays the difference between fitted values of **MeanMinT** for mid-winter versus the fall and spring average. Differences close to zero indicate little movement of the birds between climate zones, which would be expected in nonmigrants. Positive differences indicate that in mid-winter the birds are more abundant in warmer climate zones. As expected, the migratory species have a strong positive difference. The nonmigratory species have differences close to zero.

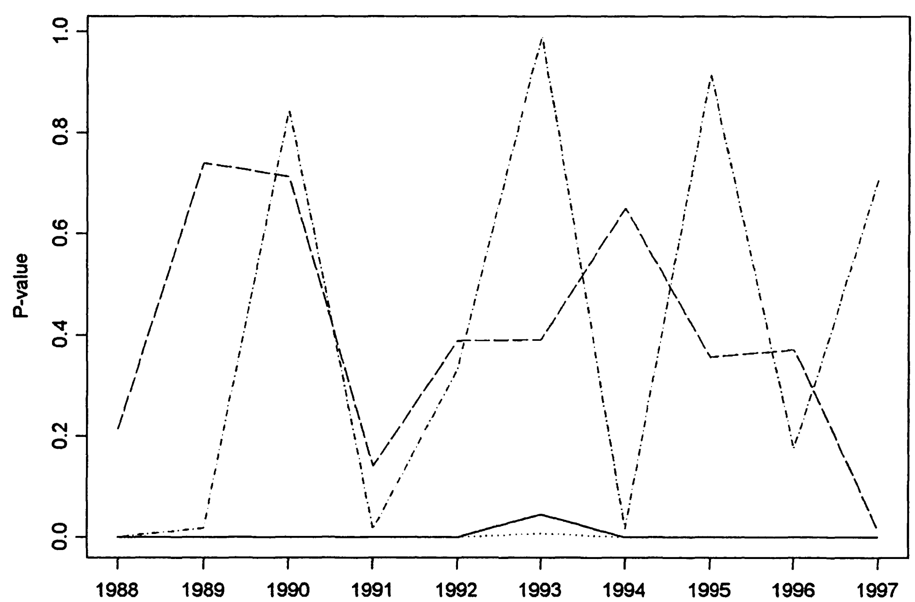

Figure 3: *A test for negative curvature of the plot of* ***MeanMinTemp*** *versus week of winter provides an index of migration. Common Grackles(solid line) and Redwing Blackbirds (dotted line) are clearly migratory on this measure with P<.05. The nonmigratory species (Downy Woodpeckers, dot-dash line, and Northern Cardinals, dashed line) have a value of this index which is greater than 0.1 in most years. However, downy woodpeckers display some migratory behavior in alternating years. Note that this measure indicates the statistical significance of the curvature, but not the magnitude of movement of the birds (which is very small for Downy Woodpeckers).*

Both methods show clear discrimination between migratory and nonmigratory species. The test for negative curvature does not indicate the size of the curvature, and hence appears to be sensitive to the very small shifts displayed by the Downy Woodpecker. The test for a mid-winter shift in **MeanMinT** includes the magnitude of the change, so that Downy Woodpeckers are not classified as migratory.

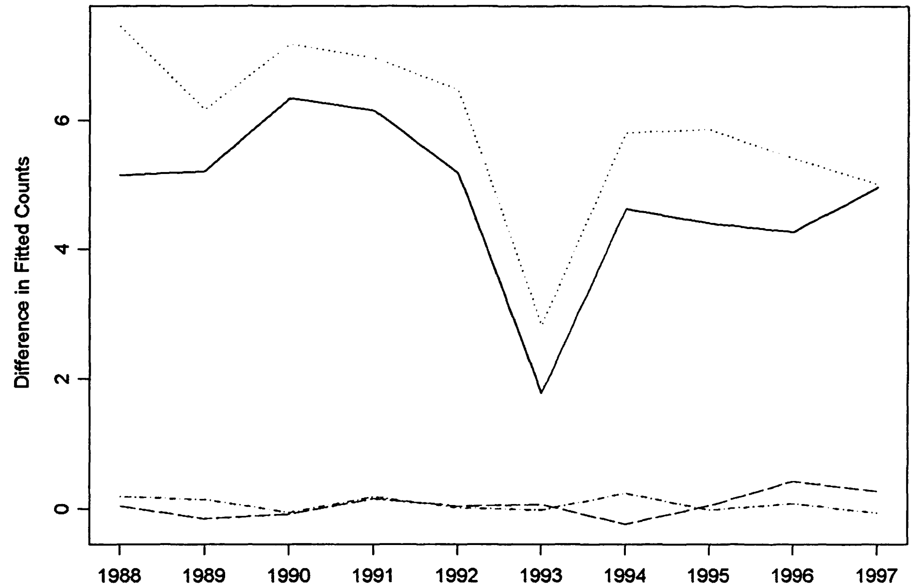

Figure 4: *The difference between fitted values in the mid-winter versus the early and late season provides an index of migration. Migratory species (Common Grackle, solid line and Redwing Blackbird, dotted line) have a large shift towards warmer climates in the mid-winter. Nonmigrant species (Northern Cardinal, dashed line, Downy Woodpeckers, dot-dash line) do not shift.*

Analysis of counts by observer

An alternative, and possibly more natural approach to understanding bird migration is to model the bi-weekly observations of each participant. Discounting weather effects, which may bring more birds to feeders during local inclement conditions, we expect that the patterns for migrants should differ by **MeanMinT**, while those for nonmigrants should not. Specifically, we expect participants in colder climates to see more migrants during the late and early season, and fewer in mid-winter, while participants in warmer climates should see fewer migrants during the late and early season, and more in mid-winter. However, the numbers of nonmigrants should be constant throughout the winter, and no climate effects should be observed. There are also several observer-specific covariates, such as the local habitat, which might influence bird abundance. However, most of these appear to be constant throughout the observation period. We chose to use a random observer effect rather than attempt to model these covariates.

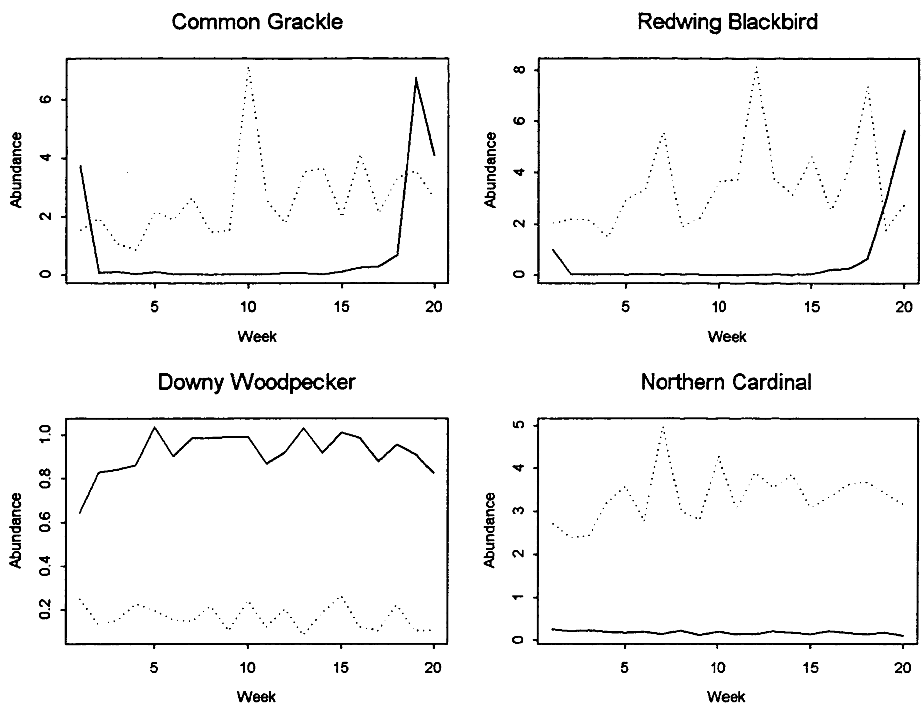

Figure 5: *Mean weekly counts for cold climate participants (solid line) and warm climate participants (dotted line).*

Figure 5 shows the mean weekly counts of each species for observers with MeanMinT < -15°C and observers with MeanMinT > 2°C. As we might expect, for the migratory species, observers in colder climate zone see fewer birds during the winter months and more in the fall and spring, while those in the warmer climate zone appear to see somewhat more birds in mid-winter. Among the nonmigrant species, Downy Woodpeckers are more abundant throughout the year in the colder zone, while Northern Cardinals are more abundant in the warmer zone. However, there is no evident seasonal effect in either zone.

We therefore considered the model

$$\text{MaxBirds}_i(\text{Week}) = \beta_0 + \beta_1{*}\text{Week} + \beta_2{*}\text{Week}^2 + \beta_3{*}\text{MeanMinT} + \beta_4{*}\text{Week}{*}\text{MeanMinT} + \beta_5{*}\text{Week}^2{*}\text{MeanMinT} + U_i + \varepsilon_i(\text{Week}) \quad (1)$$

where MeanMinT is a measure of winter severity and U_i is a random intercept unique to the observer.

We expect a climate by time interaction which indicates a "U"-shaped curve for abundance in the colder climate zones, which flattens, or changes to a "dome"-shaped curve in the warmer zones. In model (1) the index of migration is then the estimate of β_5 which should be negative in migrants and non-negative in nonmigrants. Alternatively, we can look at the curvature of the abundance curves for each value of climate, which is

$2(\beta_4+\beta_5\text{Climate})$. For migrants, this should be positive in the cold climates and negative in the warm.

Because the period of travel between summer and winter ranges is very short for the migrating species, we also fitted a model with indicator variables

$$\text{MaxBirds}_i(\text{Week})= \beta_0+ \beta_1{*}\text{Fall} +\beta_2{*}\text{MidWinter} +\beta_3{*}\text{MeanMinT}+\beta_4{*}\text{Fall}{*}\text{MeanMinT} +\beta_5{*}\text{MidWinter}{*}\text{MeanMinT}+U_i+\varepsilon_i(\text{Week}) \quad (2)$$

where Fall and MidWinter are indicator variables for weeks 1-4 and 5 to 16 respectively. This allows for a flattened "cup" or "cap" shape such as the cold climate migrant curves in Figure 5. For model (2), we expect a season by climate interaction. In particular, β_5 should be negative in migrants and non-negative in nonmigrants and is the index of migration.

The mixed model analysis gave the expected results for migrant species, Redwing Blackbird and Common Grackle for both models in all years. However, the nonmigrant Northern Cardinal also appears to behave like a migrant, with consistently negative estimates of β_5, although this was not significantly different from zero in 6 of the 10 years. The index for nonmigrant Downy Woodpecker was also predominantly negative, although nonsignificant for 5 of the 10 years.

These results indicate that this approach will not yield a sufficiently specific index to determine whether or not a species is migratory.

Discussion

A number of aspects of the data and of the biology work against our ability to distinguish between migratory and nonmigratory species.

The data are inherently noisy. Volunteer participants do not always report regularly. They may skew their observation times to periods when the feeders are particularly busy. Local weather, the presence of predators such as house cats, the type of bird food provided, and many other variables affect the presence or absence of birds at the feeder. In some regions, particularly Tompkins County, in which the Cornell Laboratory of Ornithology is located, participants may live close together, so that the same individual birds are being counted by multiple observers. Other areas of the country have very few participants, so that individual participants may have a high influence on the observed counts.

Very few participants started in 1987 and are today still participating and at the same address. The November to March observation period does not cover the full migratory cycle for some species. The spatial extent of the data may not include the summer and winter ranges of all species of interest. Extending the observation period is not feasible - feeder counts are not accurate reflections of the number of birds when natural sources of food are abundant. Extending the spatial range of the data is only minimally feasible - participants are volunteers, and gaps in the data correspond to sparsely populated sections of Canada and the U.S.

Bird behavior is not conducive to obtaining accurate estimates of population size from feeder observations. Birds forage widely. If food is sparse, as may be the case during inclement weather in the winter, they tend to congregate at feeders - otherwise they may disperse widely. It is therefore not practical to extend the observation period into the warmer months. Some species flock; others may forage individually or in small groups but flock when the weather is bad. Hence, even nonmigrants may have seasonal feeder behaviors that differ in the northern and southern part of their range. Greater mortality in the harsher climates would give a north to south pattern of seasonal abundance similar to that of a migrating species. On the other hand, increased flock size and more visits to feeders in the harsher climates would give a north to south seasonal abundance pattern diametrically opposite to that of a migrant species. Perusal of distribution maps (e.g. Peterson Field Guide to Eastern Birds) show that both the Common Grackle and Redwing Blackbird are winter-resident in much of the eastern U.S., and this is confirmed by the Project Feederwatch data. Hence, these species can be considered only partial migrants in the area in which the data were collected. In fact, even the American Robin, the so-called "harbinger of spring" is actually winter-resident over much of the eastern region.

Nonmigrant species also have episodes known as irruptions, possibly due to resource depletion. During an irruption, a large number of birds may emigrate from their home range. Although these do not return, the behavior is similar to migration behavior in terms of observed abundances. Thus, in any particular year, a nonmigrant species may appear to have migratory behavior.

Thus finding a summary statistic based on seasonal abundance that distinguishes between migratory and nonmigratory behavior is far more difficult than intuition would suggest.

On the other hand, the Project Feederwatch data, although noisy, provide a rich dataset for investigation of bird behavior. Both the temporal and spatial resolution of the data are extraordinary. Clearly a study of this scale is feasible only because of the widespread participation of thousands of volunteers across the continent. The bird-watching community participates in a number of projects throughout the year which provide spatially detailed counts of many species. Development of a quantitative index of bird movement, as outlined here, makes it possible to use these data in a meaningful way to monitor environmental use and bird behavior.

As this paper goes to press, the migration indices based on average climate zone are being applied to all of the species observed by Project Feederwatch, in all years. We expect to detect features of migration behavior and irruptions. We also hope to apply a similar index to movements more localized in time or space.

References:

Carlson, S. (1997) 'The Joys of Armchair Ornithology', *Scientific American.*

Peterson Field Guide to Eastern Birds